Fire and Fuels Science Quarterly: Summer 2012

Aquatic Wildlife

Jackson, Breeanne K., S. Mažeika P. Sullivan, and Rachel L. Malison. 2012. Wildfire severity mediates fluxes of plant material and terrestrial invertebrates to mountain streams. Forest Ecology and Management 278: 27-34.

Abstract. Wildfire effects upon riparian plant community structure, composition, and distribution may strongly influence the dynamic relationships between riparian vegetation and stream ecosystems. However, few studies have examined the influence of fire on these processes. To that end, we compared the quantity and composition of allochthonous inputs of plant material and terrestrial invertebrates among stream tributaries characterized by various degrees of burn severity 5 years post-fire in the Frank Church Wilderness of central Idaho, USA. The magnitude of inputs of coniferous leaf litter to unburned stream reaches was five times that of inputs to severely burned reaches. Deciduous leaf litter inputs to unburned reaches were 1.5 times, and inputs of terrestrial invertebrates were twice, the magnitude of inputs to severely burned reaches. NMS ordination and MRPP analysis indicated that the taxonomic composition of terrestrial invertebrate inputs to unburned stream reaches was significantly different than the composition of invertebrate inputs to either high-severity or low-severity reaches (A = 0.057, p = 0.040). Unburned and low-severity stream reaches received greater inputs of large-bodied invertebrates belonging to the orders Hymenoptera, Lepidoptera, Orthoptera, and Diptera. Taken as a whole, our results indicate that fire can significantly alter terrestrial–aquatic connectivity via alterations in riparian-to-stream inputs of leaf material and arthropods. Given these findings, wildfire severity might be expected to be a critical factor in shaping stream–riparian food webs in fire-prone areas.

Climate Change and Carbon Management

Moritz, Max A., Marc-André Parisien, Enric Batllori, Meg A. Krawchuk, Jeff Van Dorn, David J. Ganz, and Katharine Hayhoe. 2012. Climate change and disruptions to global fire activity. Ecosphere 3:art49. http://dx.doi.org/10.1890/ES11-00345.1

Abstract. Future disruptions to fire activity will threaten ecosystems and human well-being throughout the world, yet there are few fire projections at global scales and almost none from a broad range of global climate models (GCMs). Here we integrate global fire datasets and environmental covariates to build spatial statistical models of fire probability at a 0.5° resolution and examine environmental controls on fire activity. Fire models are driven by climate norms from 16 GCMs (A2 emissions scenario) to assess the magnitude and direction of change over two time periods, 2010–2039 and 2070–2099. From the ensemble results, we identify areas of consensus for increases or decreases in fire activity, as well as areas where GCMs disagree. Although certain biomes are sensitive to constraints on biomass productivity and others to atmospheric conditions promoting combustion, substantial and rapid shifts are projected for future fire activity across vast portions of the globe. In the near term, the most consistent increases in fire activity occur in biomes with already somewhat warm climates; decreases are less pronounced and concentrated primarily in a few tropical and subtropical biomes. However, models do not agree on

the direction of near-term changes across more than 50% of terrestrial lands, highlighting major uncertainties in the next few decades. By the end of the century, the magnitude and the agreement in direction of change are projected to increase substantially. Most far-term model agreement on increasing fire probabilities (~ 62%) occurs at mid- to high-latitudes, while agreement on decreasing probabilities (~20%) is mainly in the tropics. Although our global models demonstrate that long-term environmental norms are very successful at capturing chronic fire probability patterns, future work is necessary to assess how much more explanatory power would be added through interannual variation in climate variables. This study provides a first examination of global disruptions to fire activity using an empirically based statistical framework and a multi-model ensemble of GCM projections, an important step toward assessing fire-related vulnerabilities to humans and the ecosystems upon which they depend.

Pingree, Melissa R. A., Peter S. Homann, Brett Morrissette and Robyn Darbyshire. 2012. Long and Short-Term Effects of Fire on Soil Charcoal of a Conifer Forest in Southwest Oregon. Forests 3(2): 353-369. doi:10.3390/f3020353

Abstract. In 2002, the Biscuit Wildfire burned a portion of the previously established, replicated conifer unthinned and thinned experimental units of the Siskiyou Long-Term Ecosystem Productivity (LTEP) experiment, southwest Oregon. Charcoal C in pre and post-fire O horizon and mineral soil was quantified by physical separation and a peroxide-acid digestion method. The abrupt, short-term fire event caused O horizon charcoal C to increase by a factor of ten to >200 kg C ha^{-1}. The thinned wildfire treatment produced less charcoal C than unthinned wildfire and thinned prescribed fire treatments. The charcoal formation rate was 1 to 8% of woody fuels consumed, and this percentage was negatively related to woody fuels consumed, resulting in less charcoal formation with greater fire severity. Charcoal C averaged 2000 kg ha^{-1} in 0–3 cm mineral soil and may have decreased as a result of fire, coincident with convective or erosive loss of mineral soil. Charcoal C in 3–15 cm mineral soil was stable at 5500 kg C ha^{-1}. Long-term soil C sequestration in the Siskiyou LTEP soils is greatly influenced by the contribution of charcoal C, which makes up 20% of mineral soil organic C. This research reiterates the importance of fire to soil C in a southwestern Oregon coniferous forest ecosystem.

Raymond, Crystal L. and Donald McKenzie. 2012. Carbon dynamics of forests in Washington, USA: 21st century projections based on climate-driven changes in fire regimes. Ecological Applications 22:1589–1611. http://dx.doi.org/10.1890/11-1851.1

Abstract. During the 21st century, climate-driven changes in fire regimes will be a key agent of change in forests of the U.S. Pacific Northwest (PNW). Understanding the response of forest carbon (C) dynamics to increases in fire will help quantify limits on the contribution of forest C storage to climate change mitigation and prioritize forest types for monitoring C storage and fire management to minimize C loss. In this study, we used projections of 21st century area burned to explore the consequences of changes in fire regimes on C dynamics in forests of Washington State. We used a novel empirical approach that takes advantage of chronosequences of C pools and fluxes and statistical properties of fire regimes to

explore the effects of shifting age class distributions on C dynamics. Forests of the western Cascades are projected to be more sensitive to climate-driven increases in fire, and thus projected changes in C dynamics, than forests of the eastern Cascades. In the western Cascades, mean live biomass C is projected to decrease by 24–37%, and coarse woody debris (CWD) biomass C by 15–25% for the 2040s. Loss of live biomass C is projected to be lower for forests of the eastern Cascades and Okanogan Highlands (17–26%), and CWD biomass is projected to increase. Landscape mean net primary productivity is projected to increase in wet low-elevation forests of the western Cascades, but decrease elsewhere. These forests, and moist forests of the Okanogan Highlands, are projected to have the greatest percentage increases in consumption of live biomass. Percentage increases in consumption of CWD biomass are greater than 50% for all regions and up to four times greater than increases in consumption of live biomass. Carbon sequestration in PNW forests will be highly sensitive to increases in fire, suggesting a cautious approach to managing these forests for C sequestration to mitigate anthropogenic CO_2 emissions.

Fire Behavior and Fuels

Arkle, Robert S., David S. Pilliod, and Justin L. Welty. 2012. Pattern and process of prescribed fires influence effectiveness at reducing wildfire severity in dry coniferous forests. Forest Ecology and Management 276: 174-184.

Abstract. We examined the effects of three early season (spring) prescribed fires on burn severity patterns of summer wildfires that occurred 1–3 years post-treatment in a mixed conifer forest in central Idaho. Wildfire and prescribed fire burn severities were estimated as the difference in normalized burn ratio (dNBR) using Landsat imagery. We used GIS derived vegetation, topography, and treatment variables to generate models predicting the wildfire burn severity of 1286–5500 30-m pixels within and around treated areas. We found that wildfire severity was significantly lower in treated areas than in untreated areas and significantly lower than the potential wildfire severity of the treated areas had treatments not been implemented. At the pixel level, wildfire severity was best predicted by an interaction between prescribed fire severity, topographic moisture, heat load, and pre-fire vegetation volume. Prescribed fire severity and vegetation volume were the most influential predictors. Prescribed fire severity, and its influence on wildfire severity, was highest in relatively warm and dry locations, which were able to burn under spring conditions. In contrast, wildfire severity peaked in cooler, more mesic locations that dried later in the summer and supported greater vegetation volume. We found considerable evidence that prescribed fires have landscape-level influences within treatment boundaries; most notable was an interaction between distance from the prescribed fire perimeter and distance from treated patch edges, which explained up to 66% of the variation in wildfire severity. Early season prescribed fires may not directly target the locations most at risk of high severity wildfire, but proximity of these areas to treated patches and the discontinuity of fuels following treatment may influence wildfire severity and explain how even low severity treatments can be effective management tools in fire-prone landscapes.

Cochrane, M. A., C. J. Moran, M. C. Wimberly, A. D. Baer, M. A. Finney, K. L. Beckendorf, J. Eidenshink and Z. Zhu. 2012. Estimation of wildfire size and risk changes due to fuels treatments. International Journal of Wildland Fire 21(4): 357-367. http://dx.doi.org/10.1071/WF11079

Abstract. Human land use practices, altered climates, and shifting forest and fire management policies have increased the frequency of large wildfires several-fold. Mitigation of potential fire behaviour and fire severity have increasingly been attempted through pre-fire alteration of wildland fuels using mechanical treatments and prescribed fires. Despite annual treatment of more than a million hectares of land, quantitative assessments of the effectiveness of existing fuel treatments at reducing the size of actual wildfires or how they might alter the risk of burning across landscapes are currently lacking. Here, we present a method for estimating spatial probabilities of burning as a function of extant fuels treatments for any wildland fire-affected landscape. We examined the landscape effects of more than 72 000 ha of wildland fuel treatments involved in 14 large wildfires that burned 314 000 ha of forests in nine US states between 2002 and 2010. Fuels treatments altered the probability of fire occurrence both positively and negatively across landscapes, effectively redistributing fire risk by changing surface fire spread rates and reducing the likelihood of crowning behaviour. Trade offs are created between formation of large areas with low probabilities of increased burning and smaller, well-defined regions with reduced fire risk.

Dunn, Christopher J. and John D. Bailey. 2012. Temporal dynamics and decay of coarse wood in early seral habitats of dry-mixed conifer forests in Oregon's Eastern Cascades. Forest Ecology and Management 276: 71-81.

Abstract. Early seral forest habitats are increasingly valued for the unique structural resources they provide in many western US forests. Coarse woody detritus (CWD) are a significant feature of this developmental stage and are highly dynamic, suggesting these environments exhibit temporally diverse structural conditions prior to forest canopy closure. In dry-mixed conifer forests, snags are hypothesized to decay slower than logs making long-term dynamics in these forests dependent on snag fall, breakage and the decay rates of both standing and surface CWD. We estimated snag fall and breakage rates for *Pinus ponderosa*, *Abies* sp., *P. menziesii* and *P. contorta* snags in three diameter classes (<23 cm, 23–41 cm and > 41 cm) from 6057 snags across a 24-year chronosequence of early seral environments. Snag and log decay rates were estimated by felling 60 *Abies* sp. and 60 *P. ponderosa* snags, and sampling 40 *P. ponderosa* logs. Half-life estimates for snags <23 cm, 23–41 cm, and >41 cm were 7, 12, and 17 years for *Pinus* sp., 10, 15, and 20 years for *Abies* sp., and 11, 17, and 23 years for *P. menziesii*. Breakage rates were lowest for small snags and not significantly different for medium and large snags, but did vary across species. We estimated an *Abies* sp. snag decomposition loss-rate constant of $k = 0.0179\ \mathrm{yr}^{-1}$ (SE = 0.00533, *p*-value = 0.0014) but *P. ponderosa* snags did not exhibit statistically significant decay ($k = 0.0024\ \mathrm{yr}^{-1}$, SE = 0.00518, *p*-value = 0.6414). *P. ponderosa* logs had an estimated decomposition loss-rate constant of $k = 0.0243\ \mathrm{yr}^{-1}$ (SE = 0.0073, *p*-value = 0.0023), confirming reduced decay rates in snags and variation among species. Following high-severity fire, dry-mixed conifer stands experience relatively rapid temporal changes in CWD resources largely dependent on snag species and diameter-at-breast-height (DBH). Variation in fall, breakage and decay rates among species and DBH suggests maintaining a diverse selection of snag species and diameters would meet multiple ecological needs across a broader temporal scale.

Additionally, given the rapid temporal changes in CWD, defining early seral habitat as the period immediately following disturbance until canopy closure may not adequately account for the diversity in habitat structures and resources available over time.

Graham, Russell; Finney, Mark; McHugh, Chuck; Cohen, Jack; Calkin, Dave; Stratton, Rick; Bradshaw, Larry; Nikolov, Ned. 2012. Fourmile Canyon Fire Findings. Gen. Tech. Rep. RMRS-GTR-289. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 110 p. Available at http://www.fs.fed.us/rm/pubs/rmrs_gtr289.html.

Abstract. The Fourmile Canyon Fire burned in the fall of 2010 in the Rocky Mountain Front Range adjacent to Boulder, Colorado. The fire occurred in steep, rugged terrain, primarily on privately owned mixed ponderosa pine and Douglas-fir forests. The fire started on September 6 when the humidity of the air was very dry (≈ <7%) and the winds were steadily blowing in the range of 15 miles per hour and gusting to over 40 miles per hour. These conditions prevailed for most of the first day when the fire burned approximately 5,700 acres and destroyed 162 homes. Because of the windy conditions, aircraft could not be used until late that first day. The first responders concentrated on evacuating the occupants of the 474 homes in the fire vicinity. No public or firefighters were injured during the course of the fire. This outcome was directly related to the excellent preparedness of Boulder County and, in particular, the Sheriff's Department and the local fire districts. Fuel treatments had previously been applied to several areas within the fire perimeter to modify fire behavior and/or burn severity if a wildfire was to occur. However, the fuel treatments had minimal impact in affecting how the fire burned or the damage it caused. After the initial day of intense burning and 4 additional days of relatively benign fire behavior, the Fourmile Canyon Fire had burned 6,181 acres and become one of the most damaging fires in Colorado's history. This report summarizes how the fire burned, the damage it caused, and offers insights to help the residents and first responders prepare for the next wildfire that will burn on the Colorado Front Range.

Hudec, Jessica L. and David L. Peterson. 2012. Fuel variability following wildfire in forests with mixed severity fire regimes, Cascade Range, USA. Forest Ecology and Management 277: 11-24.

Abstract. Fire severity influences post-burn structure and composition of a forest and the potential for a future fire to burn through the area. The effects of fire on forests with mixed severity fire regimes are difficult to predict and interpret because the quantity, structure, and composition of forest fuels vary considerably. This study examines the relationship between fire severity and post-burn fuel characteristics in forests with mixed severity fire regimes. We sampled live and dead canopy and surface fuels across four fire severity classes on three wildfires that occurred on the east side of the Cascade Range, USA, in 2007 and 2008. We used empirical fuels data and stand structure and composition characteristics to calculate potential surface fire behavior for the four fire severity classes. Post-burn average canopy cover is 25–30% in the low severity class and <10% in the high severity class and ranges from 0 to 50% for all fires. All variables representing post-burn canopy fuels differ by fire severity class. The average loading of dead and down woody fuels <7.6 cm diameter and litter is 0.9–1.1 kg m^{-2} in the low severity class and 0.6–0.8 kg m^{-2} in the high severity class. Values for fuel loading variables span a wide

range of values within and among fires, and substantial overlap exists among severity classes. Fire severity generally does not influence post-burn dead and down woody fuel loading. Estimates of potential fire behavior also cover wide ranges of values, particularly among fires. Flame lengths average 0.4–0.8 m in the low severity classes and 0.3–1.1 m in the high severity classes. The range of potential flame length values, modeled with a 16.1 km h^{-1} midflame wind speed, varies by up to 2.0 m within a single severity class (0.6–2.6 m). Fire severity does influence potential fire behavior, but typically just one severity class differs from the other three classes. These results indicate that fire severity influences immediate (2–3 years) post-burn canopy fuels and potential fire behavior but does not influence dead and down surface fuel loading for the three fires studied. The wide ranges of values for the fuel components analyzed demonstrate the variability that is characteristic of forests with mixed severity fire regimes and emphasize the need to consider the natural heterogeneity of these forests in fire and fuels management. Quantification of post-burn fuel variability is critical for understanding the ecological significance of mixed severity fires and developing restoration strategies that emulate characteristics of the historical fire regime.

Hyde, Joshua C., Alistair M. S. Smith and Roger D. Ottmar. 2012. Properties affecting the consumption of sound and rotten coarse woody debris in northern Idaho: a preliminary investigation using laboratory fires. International Journal of Wildland Fire 21(5): 596-608. http://dx.doi.org/10.1071/WF11016

Abstract. This study evaluates the consumption of coarse woody debris in various states of decay. Samples from a northern Idaho mixed-conifer forest were classified using three different classification methods, ignited with two different ignition methods and consumption was recorded. Intrinsic properties that change with decay were measured including carbon to nitrogen ratio, density, heat content, lignin content, moisture content and surface area-to-volume ratio. Consumption for logs in different stages of decay is reported with characterisation of wood properties. Results indicate very decayed coarse woody debris is likely to be consumed to a substantially greater degree than sound coarse woody debris given similar conditions. High consumption occurred in debris with low-density, high-lignin content and high gravimetric heat content; however, lignin content and density showed the highest correlation with consumption. The Maser classification method grouped very rotten logs with high consumption into decay class 4 and the remainder into class 3. Trends in consumption were similar regardless of ignition; however low-intensity long-duration ignition produced higher consumption values. Focus on physical properties is recommended for predictive purposes over any classification method. Logs of other species and in regions with different decomposition and combustion dynamics may display different property ranges and consumption results.

Jenkins, Michael J., Wesley G. Page, Elizabeth G. Hebertson, Martin E. Alexander. 2012. Fuels and fire behavior dynamics in bark beetle-attacked forests in Western North America and implications for fire management. Forest Ecology and Management 275: 23-24.

Abstract. Declining forest health attributed to associations between extensive bark beetle-caused tree mortality, accumulations of hazardous fuels, wildfire, and climate change have catalyzed changes in forest health and wildfire protection policies of

land management agencies. These changes subsequently prompted research to investigate the extent to which bark beetle-altered fuel complexes affect fire behavior. Although not yet rigorously quantified, the results of the investigations, in addition to a growing body of operational experience, indicate that predictable changes in surface, ladder and canopy fuel characteristics do occur over the course of a bark beetle rotation. Input of these changes in fuel characteristics into conventional fire behavior modeling systems can readily provide predictions of potential fire behavior, including the likelihood of crowning. However, several factors limit the direct application of these modeling systems in their current form and consequently, they may largely under predict fire potential in such stands. This presents a concern where extreme fire behavior involving both crowning and spotting coupled with flammable fuel conditions can pose serious challenges to incident management and threaten the safety of firefighters and the general public alike. In this paper, we review the nature and characteristics of bark beetle-altered fuel complexes in the conifer forests of the Interior West and the challenges of understanding the effects on extreme fire behavior, including the initiation and spread of crown fires. We also discuss how emerging fire management plans in the U.S. have begun to integrate wildfire management and other forest health objectives with the specific goal of achieving biodiversity and ecosystem resiliency while simultaneously reducing the existence of hazardous fuel complexes.

Page, Wesley G., Michael J. Jenkins, and Justin B. Runyon. 2012. Mountain pine beetle attack alters the chemistry and flammability of lodgepole pine foliage. Canadian Journal of Forest Research 42(8): 1631-1647, 10.1139/x2012-094.

Abstract. During periods with epidemic mountain pine beetle (*Dendroctonus ponderosae* Hopkins) populations in lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) forests, large amounts of tree foliage are thought to undergo changes in moisture content and chemistry brought about by tree decline and death. However, many of the presumed changes have yet to be quantified. In this study, we quantified and compared fuel moisture, chemistry, and resulting flammability of bark beetle affected foliage in terms of ignitability, combustibility, consumability, and sustainability at a site in far eastern Idaho, USA. Results revealed substantial decreases in moisture content, the proportion of starches and sugars, and crude fat and increases in the proportions of lignin, cellulose, and hemicellulose in foliage of trees attacked in the previous year (yellow foliage) or more than two years previously (red foliage). Increases in emission rates of several terpenes that were correlated with flammability were also detected in yellow foliage. The flammability of fresh yellow and red foliage increased with regard to ignitability and sustainability, with shorter times to ignition, lower temperatures at ignition, and higher heat yields when compared with unattacked green foliage. Our results confirm the overwhelming importance of fuel moisture on flammability and suggest that fuel chemical composition also has significant effects on lodgepole pine foliage flammability.

Parisien, Marc-André, Susan Snetsinger, Jonathan A. Greenberg, Cara R. Nelson, Tania Schoennagel, Solomon Z. Dobrowski and Max A. Moritz. 2012. Spatial variability in wildfire probability across the western United States. International Journal of Wildland Fire 21(4): 313-327 http://dx.doi.org/10.1071/WF11044

Abstract. Despite growing knowledge of fire–environment linkages in the western USA, obtaining reliable estimates of relative wildfire likelihood remains a work in progress. The purpose of this study is to use updated fire observations during a 25-year period and a wide array of environmental variables in a statistical framework to produce high-resolution estimates of wildfire probability. Using the MaxEnt modelling technique, point-source fire observations that were sampled from area burned during the 1984–2008 time period were related to explanatory variables representing ignitions, flammable vegetation (i.e. fuels), climate and topography. Model results were used to produce spatially explicit predictions of wildfire probability. To assess the effect of humans on the spatial patterns of wildfire likelihood, we built an alternative model that excluded all variables having a strong anthropogenic imprint. Results showed that wildfire probability in the western USA is far from uniform, with different areas responding to different environmental drivers. The effect of anthropogenic factors on wildfire probability varied by region but, on the whole, humans appear to inhibit fire activity in the western USA. Our results not only provide what appear to be robust predictions of wildfire likelihood, but also enhance understanding of long-term controls on wildfire activity. In addition, our wildfire probability maps provide better information for strategic planning of land-management activities, especially where fire regime knowledge is sparse.

Safford, H.D., J.T. Stevens, K. Merriam, M.D. Meyer, and A.M. Latimer. 2012. Fuel treatment effectiveness in California yellow pine and mixed conifer forests. Forest Ecology and Management 274: 17-28.

Abstract. We assessed the effectiveness of forest fuel thinning projects that explicitly removed surface and ladder fuels (all but one were combined mechanical and prescribed fire/pile burn prescriptions) in reducing fire severity and tree mortality in 12 forest fires that burned in eastern and southern California between 2005 and 2011. All treatments and fires occurred in yellow pine or mixed conifer forests, in a variety of landscape conditions. Most fires burned under warm, dry conditions, with moderate to high winds. With few exceptions, fire severity measures (bole char height, scorch and torch height, scorch and torch percentage) and tree mortality were much lower in forest stands treated for fuels than in neighboring untreated stands. Fire-tolerant species like *Pinus jeffreyi* and *Pinus ponderosa* exhibited much higher postfire survivorship than fire-intolerant species like *Abies concolor.* Among variables related to fire weather, fuel loading, and treatment age, ten-hour fuel moisture was found to be a better predictor of tree survival in untreated stands than in treated stands, while fuel loading was a better predictor of survival in treated stands. We did not find an effect of treatment age, but our oldest treatments (nine years when burned) were below the mean pre-Euroamerican settlement fire return interval for these forest types. Within treatments, fire severity decreased with distance from the treatment boundary, and canopy fires were almost always reduced to surface fires within 70 m of entering the treatment. In California yellow pine and mixed conifer forests, treatment prescriptions should allow for levels of fire-driven canopy tree mortality (c. 5–15%) that better mimic natural fires. Our results add significantly to the growing evidence that fuel treatments that include removal of surface and ladder fuels in these forest

types are highly effective management tools for reducing fire severity and canopy tree mortality. In our opinion, quantitative assessments of fuel treatment effects on fire severity in frequent-fire forest types hardly merit further effort. Rather, we suggest that future work focus on documenting and comparing other ecological outcomes of fuel treatments in burned and unburned forest, such as effects on plant and animal diversity, soil conditions, and habitat heterogeneity.

Stephens, Scott L., James D. McIver, Ralph E. J. Boerner, Christopher J. Fettig, Joseph B. Fontaine, Bruce R. Hartsough, Patricia L. Kennedy and Dylan W. Schwilk. 2012. The Effects of Forest Fuel-Reduction Treatments in the United States. BioScience 62(6): 549–560.

Abstract. The current conditions of many seasonally dry forests in the western and southern United States, especially those that once experienced low- to moderate-intensity fire regimes, leave them uncharacteristically susceptible to high-severity wildfire. Both prescribed fire and its mechanical surrogates are generally successful in meeting short-term fuel-reduction objectives such that treated stands are more resilient to high-intensity wildfire. Most available evidence suggests that these objectives are typically accomplished with few unintended consequences, since most ecosystem components (vegetation, soils, wildlife, bark beetles, carbon sequestration) exhibit very subtle effects or no measurable effects at all. Although mechanical treatments do not serve as complete surrogates for fire, their application can help mitigate costs and liability in some areas. Desired treatment effects on fire hazards are transient, which indicates that after fuel-reduction management starts, managers need to be persistent with repeated treatment, especially in the faster-growing forests in the southern United States.

Wei, Yu. 2012. Optimize landscape fuel treatment locations to create control opportunities for future fires. Canadian Journal of Forest Research 42(6): 1002-1014, 10.1139/x2012-051.

Abstract. Fuel treatment can improve the efficiency of controlling future catastrophic fires. Selecting optimal fuel treatment locations across a landscape is a challenging strategic planning problem in wildland fire management. This research develops a new fuel treatment optimization model by extending a fire suppression model to simultaneously consider many future fires. Fire is ignited from every grid cell in a landscape and modeled for various durations in a mixed integer programming model. Fuel treatment in a cell decreases its fire intensity and makes future fire control effective in it. This model allocates fuel treatments to minimize the total landscape future fire loss. It was first tested on several artificial landscapes for model validation. Results show that it tends to allocate fuel treatments in contiguous areas following regular and intuitive spatial patterns. Spatial fuel treatment layouts vary according to the change of fire ignition probability distribution, the distribution of value to be protected from fire, and fire duration assumptions. Trade-off between protecting different parts of a landscape is a major driver in designing fuel treatment layouts. A test case in the Sequoia and Kings Canyon national parks demonstrates how this model assembles spatial information and helps study the effects of fuel treatments in a heterogeneous landscape. This model allows managers to assemble information from many possible future fires to make informative strategic-level fuel treatment decisions. A potential model extension and the limitations of this model are also discussed.

Forests

Estes, Becky L., Eric E. Knapp, Carl N. Skinner and Fabian C. C. Uzoh. 2012. Seasonal variation in surface fuel moisture between unthinned and thinned mixed conifer forest, northern California, USA. International Journal of Wildland Fire 21(4): 428-435. http://dx.doi.org/10.1071/WF11056

Abstract. Reducing stand density is often used as a tool for mitigating the risk of high-intensity crown fires. However, concern has been expressed that opening stands might lead to greater drying of surface fuels, contributing to increased fire risk. The objective of this study was to determine whether woody fuel moisture differed between unthinned and thinned mixed-conifer stands. Sections of logs representing the 1000- and 10 000-h fuel sizes were placed at 72 stations within treatment units in the fall (autumn) of 2007. Following snow-melt in 2008, 10-h fuel sticks were added and all fuels were weighed every 1–2 weeks from May until October. Moisture of the 1000- and 10 000-h fuels peaked at the end of May, and then decreased steadily through the season. Moisture of the 10- and 1000-h fuels did not differ between unthinned and thinned stands at any measurement time. The 10 000-h fuel moisture was significantly less in thinned than unthinned stands only in early to mid-May. Overall, even when fuel moisture varied between treatments, differences were small. The long nearly precipitation-free summers in northern California appear to have a much larger effect on fuel moisture than the amount of canopy cover. Fuel moisture differences resulting from stand thinning would therefore not be expected to substantially influence fire behaviour and effects during times of highest fire danger in this environment.

Fulé, Peter Z., Larissa L. Yocom, Citlali Cortés Montaño, Donald A. Falk, Julián Cerano, and José Villanueva-Díaz. 2012. Testing a pyroclimatic hypothesis on the Mexico–United States border. Ecology 93:1830–1840. http://dx.doi.org/10.1890/11-1991.1

Abstract. The "pyroclimatic hypothesis" proposed by F. Biondi and colleagues provides a basis for testable expectations about climatic and other controls of fire regimes. This hypothesis asserts an a priori relationship between the occurrence of widespread fire and values of a relevant climatic index. Such a hypothesis provides the basis for predicting spatial and temporal patterns of fire occurrence based on climatic control. Forests near the Mexico–United States border offer a place to test the relative influence of climatic and other controls in mountain ranges that are ecologically similar and subject to broadly similar top-down climatic influence, but with differing cultural influences. We tested the pyroclimatic hypothesis by comparing fire history information from the Mesa de las Guacamayas, a mountain range in northwestern Chihuahua, with previously published fire data from the Chiricahua Mountains, in southeastern Arizona, approximately 150 km away. We developed a priori hypothetical models of fire occurrence and compared their performance to empirical climate-based models. Fires were frequent at all Mesa de las Guacamayas study sites through the mid-20th century and continued uninterrupted to the present at one site, in contrast to nearly complete fire exclusion after 1892 at sites in the Chiricahua Mountains. The empirical regression models explained a higher proportion of the variability in fire regime associated with climate than did the a priori models. Actual climate–fire relationships diverged in each

country after 1892. The a priori models predicted continuing fires at the same rate per century as prior to 1892; fires did in fact continue in Mexico, albeit with some alteration of fire regimes, but ceased in the United States, most likely due to changes in land use. The cross-border comparison confirms that a frequent-fire regime could cease without a climatic cause, supporting previous arguments that bottom-up factors such as livestock grazing can rapidly and drastically alter surface fire regimes. Understanding the historical patterns of climate controls on fire could inform the use of historical data as ecological reference conditions and for future sustainability.

Knapp, Eric E., C. Phillip Weatherspoon, and Carl N. Skinner. 2012. Shrub Seed Banks in Mixed Conifer Forests of Northern California and the Role of Fire in Regulating Abundance. Fire Ecology 8(1): **:** 32-48. DOI: 10.4996/fireecology.0801032

Abstract. Understory shrubs play important ecological roles in forests of the western US, but they can also impede early tree growth and lead to fire hazard concerns when very dense. Some of the more common genera (*Ceanothus, Arctostaphylos,* and *Prunus*) persist for long periods in the seed bank, even in areas where plants have been shaded out. To determine shrub seed density and investigate the feasibility of managing shrub abundance by regulating the size of the soil seed bank with fire, we sampled the seed bank in 24 mixed conifer forest stands throughout northern California. Twenty stands were unburned, two had recently burned in wildfires, and two (McCloud and Jennie Springs) were subjected to experimental prescribed fires with unburned controls. Seeds were extracted from duff and soil that was collected in six layers, to a depth of 10 cm in the mineral soil. *Ceanothus* seeds were the most abundant (mean = 246 seeds m^{-2}), noted at all sites and at 88 % of sampling locations within unburned sites. *Arctostaphylos* and *Prunus* seeds were less abundant (mean = 29 seeds m^{-2} and 6 seeds m^{-2}, respectively), but still recorded at 64 % and 45 % of the unburned sites, respectively. The depth of seed burial varied at all unburned sites, but some seed was present even at the deepest (6 cm to 10 cm) soil layer, where seed mortality due to heat from burning is least likely. Seed density was substantially reduced, but not eliminated, by October prescribed burns at both McCloud and Jennie Springs, while seed density following July burns at Jennie Springs did not differ from the control. The abundance of buried seed indicates that restoring shrubs to forest understory should be possible even in areas where they are currently lacking. If preventing shrubs from colonizing a site is the management goal, the effectiveness of a single prescribed fire may be limited.

Staver, A. Carla and Simon A. Levin. 2012. Integrating Theoretical Climate and Fire Effects on Savanna and Forest Systems. The American Naturalist 180(2): 211-224.

Abstract. The role of fire and climate in determining savanna and forest distributions requires comprehensive theoretical reevaluation. Empirical studies show that climate constrains maximum tree cover and that fire feedbacks can reduce tree cover substantially, but neither the stability nor the dynamics of these systems are well understood. A theoretical integration of rainfall effects with fire processes in particular is lacking. We use simple, well-supported assumptions about the percolation dynamics of fire spread and the demographic effects of climate and fire on trees to build a dynamic model examining the stability of tree cover in savannas

and forests. Fire results in the potential for one or possibly two stable equilibria, while the effects of increasing rainfall on tree demography result in (discontinuous) increases in tree cover and in forest tree dominance. As rainfall increases, the system moves from (1) stable low tree cover to (2) bistability of low and high tree cover to (3) stable high tree cover. Thus, theory suggests that tree cover uniquely determined by climate at low and high rainfall but determined by fire feedbacks at intermediate rainfall—as empirical studies suggest—may be a universal feature of systems where fire has strong effects on tree demography.

Thies, Walter G. and Douglas J. Westlind. 2012. Validating the Malheur model for predicting ponderosa pine post-fire mortality using 24 fires in the Pacific Northwest, USA. International Journal of Wildland Fire 21(5): 572-582. http://dx.doi.org/10.1071/WF10091

Abstract. Fires, whether intentionally or accidentally set, commonly occur in western interior forests of the US. Following fire, managers need the ability to predict mortality of individual trees based on easily observed characteristics. Previously, a two-factor model using crown scorch and bole scorch proportions was developed with data from 3415 trees for predicting the probability of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) mortality following prescribed fire. Here, we report validation of that model for broader application using data from 10 109 ponderosa pines in 17 prescribed fires and 7 wildfires, observed for 3 years post-fire, from east of the Cascade Range crest in Washington, Oregon and northern California. The overall rate of correct classification was 87.1% and the rate of correctly predicting mortality was 80.1%. Similar accuracy is reported when testing the model for small trees (<53.3-cm diameter at breast height), wildfire, prescribed fire, and when using a field guide that simplifies application of the model. For large trees (≥53.3-cm diameter at breast height), the overall rate of correct prediction was 93.6% and the rate of correctly predicting mortality was 65.2%. These results suggest the Malheur model is useful for predicting ponderosa pine mortality following fires in this region.

Postfire Recovery

Donato, D. C., Campbell, J. L., Franklin, J. F. 2012. Multiple successional pathways and precocity in forest development: can some forests be born complex? Journal of Vegetation Science 23: 576–584. doi: 10.1111/j.1654-1103.2011.01362.x

Background. In forests subject to stand-replacing disturbances, conventional models of succession typically overlook early-seral stages as a simple re-organization/establishment period. These models treat structural development in essentially 'relay floristic' terms, with structural complexity (three-dimensional heterogeneity) developing primarily in old-growth stages, only after a closed-canopy 'self-thinning' phase and subsequent canopy gap formation. However, is it possible that early-successional forests can sometimes exhibit spatial complexity similar to that in old-growth forests – i.e. akin to an 'initial floristic' model of structural development?

Hypothesis. Based on empirical observations, we present a hypothesis regarding an important alternative pathway in which protracted or sparse forest establishment

and interspecific competition thin out tree densities early on – thereby precluding overstorey canopy closure or a traditionally defined self-thinning phase. Although historically viewed as an impediment to stand development, we suggest this process may actually advance certain forms of structural complexity. These young stands can exhibit qualities typically attributed only to old forests, including: (1) canopy gaps associated with clumped and widely spaced tree stems; (2) vertically heterogeneous canopies including under- and mid-stories, albeit lower stature; (3) co-existence of shade-tolerant and intolerant species; and (4) abundant dead wood. Moreover, some of these qualities may persist through succession, meaning that a significant portion of eventual old-growth spatial pattern may already be determined in this early stage.

Implications. The relative frequency of this open-canopy pathway, and the degree to which precocious complexity supports functional complexity analogous to that of old forests, are largely unknown due to the paucity of naturally regenerating forests in many regions. Nevertheless, recognition of this potential is important for the understanding and management of early-successional forests.

Restoration

Carr, Craig A. and William C. Krueger. 2012. The Role of the Seed Bank in Recovery of Understory Species in an Eastern Oregon Ponderosa Pine Forest . Northwest Science 86(3): 168-178.

Abstract. Restoration treatments in ponderosa pine forests may not promote understory recovery where residual understory plant abundance or propagule availability is insufficient for natural re-establishment. The value of the seed bank for understory recovery in Pacific Northwest ponderosa pine forests is not fully understood, therefore, we designed this study to evaluate the potential of the seed bank as a source of desired herbaceous understory species recruitment. Seed bank samples were collected from 14 ponderosa pine stands, seven with a perennial bunchgrass dominated understory (intact) and seven with little or no understory (depauperate). Seedling emergence methods were used to estimate the germinable seed bank; seedling density and diversity comparisons were made using non-parametric Wilcoxon rank-sum tests; and seedling species composition compared using multiple response permutation procedures. Comparisons were also made between seed bank and understory vegetation species composition. No statistical differences were observed in seedling density or diversity, but the intact group appeared higher in both. Seedling species composition differed between the two groups and in both groups several species present in the seed bank were also present in the corresponding understory vegetation. However, species that germinated from the seed bank of the depauperate understory group did not include any of the predominant species in the standing vegetation of the intact group indicating that a suitable propagule source for understory recovery is not available in dense ponderosa pine forests with severely degraded understories. Direct seeding of desired understory vegetation should be considered in ponderosa pine restoration activities.

Eldridge, J. D., Redente, E. F. and Paschke, M. 2012. The Use of Seedbed Modifications and Wood Chips to Accelerate Restoration of Well Pad Sites in Western Colorado, U.S.A. Restoration Ecology 20: 524–531. doi: 10.1111/j.1526-100X.2011.00783.x

Abstract. Semiarid ecosystems of Western North America are experiencing a boom in natural gas development. However, these systems are slow to recover from the disturbances created. The purpose of this study was to develop improved restoration techniques on natural gas well pads in Western Colorado. This study examined effects and interactions of seedbed modifications, soil amendments, seed mixtures, and seeding methods. The experiment was conducted in pinyon-juniper and semidesert shrub plant communities on five natural gas well pads beginning in 2006. Soil and plant cover data were collected to assess the effectiveness of 16 different treatment combinations. After two growing seasons, we found that patches of soil salinity (>4 dS/m) reduced plant cover to less than 20% on 55 of our 240 experimental plots. These patches of salinity, such as where reserve pits were buried, may need to be treated to completely restore cover on the total gas pad area, although causes of salinity patches needs further investigation. After removing the 55 saline plots from our data analyses, we found that wood chips (WC) as a soil amendment increased organic matter content and reduced non-native species. Rough seedbed modifications increased the establishment of native species, especially during years of below average precipitation. Island broadcasting resulted in an increase of noxious plant cover during the second growing season. From these findings we recommend that disturbed well pads in a similar environment be restored by seeding native species on sites that are amended with WC and physically modified to create a roughened seedbed.

James, J. J., M. J. Rinella, and T. Svejcar. 2012. Grass Seedling Demography and Sagebrush Steppe Restoration. Rangeland Ecology and Management 65(4): 409-417.

Abstract. Seeding is a key management tool for arid rangeland. In these systems, however, seeded species often fail to establish. A recent study in Wyoming big sagebrush steppe suggested that over 90% of seeded native grass individuals die before seedlings emerged. This current study examines the timing and rate of seed germination, seedling emergence, and seedling death related to this demographic bottleneck. We seeded monocultures of two native perennial bunchgrasses, *Pseudoroegenaria spicata* (Pursh) Á. Löve and *Elymus elymoides* (Raf.) Swezey, and one introduced bunchgrass, *Agropyron desertorum* (Fisch. ex Link) Schult., in 2007, 2008, and 2009 and tracked sown seed and seedling fate. Across the study years and species we found that germination was rapid and high, with species obtaining 50% germination by December, less than 2 mo after planting. Emergence of germinated seed did not occur until late February for *A. desertorum* and March for the two native grasses. In 2007 the majority of emergence and death was constrained to several weeks, whereas in 2008 and 2009 emergence and death was distributed across several months. The timing of seedling emergence did not influence survival probability or midday plant water potential (probability of exceedance <0.05). Survival probabilities once seedlings emerged were greater for native species (0.71) than *A. desertorum* (0.51) in 2 of the 3 study yr (probability of exceedance >0.98). The early germination of grasses following fall seeding, and the long 2- to 3-mo period that germinated grass seed remain in the soil before emerging, support the hypothesis that seedling recruitment might be limited largely by ecological processes and conditions during winter or early spring (such as soil

freeze–thaw events, seed pathogens, or physical crusts). Delaying seeding to early winter or spring and other management tools that mitigate these factors driving this bottleneck might greatly improve restoration outcomes in these systems.

Kyser, Guy B., Vanelle F. Peterson, Josh S. Davy, and Joseph M. DiTomaso. 2012. Preemergent Control of Medusahead on California Annual Rangelands With Aminopyralid. Rangeland Ecology and Management 65(4): 418-425.

Abstract. Medusahead (*Taeniatherum caput-medusae* [L.] Nevski), the most problematic invasive grass on many California rangelands, is difficult to control selectively in grasslands. Prescribed burning, grazing, and herbicides have been tested with some success but are not practical in all situations. The selective herbicide aminopyralid, normally used for control of certain broadleaf species such as thistles, suppresses some annual grasses when applied pre- or early postemergence. In 2009–2010, we tested the efficacy of aminopyralid for medusahead control in preemergence applications at three foothill rangeland sites in northern California. We compared a rate series of aminopyralid (53, 88, 123, and 245 $g \cdot ha^{-1}$ acid equivalent [ae]) with rimsulfuron (18 and 35 $g \cdot ha^{-1}$ active ingredient) and imazapic (140 $g \cdot ha^{-1}$ ae). Plots were 3×9 m with four replications at each site. Treatments were applied in early fall 2009. In May 2010, we took visual cover estimates and biomass/seedhead samples in three quadrats per plot. In regression analysis, medusahead cover was found to decrease consistently with increasing rates of aminopyralid. Medusahead control at the highest rates of aminopyralid was consistent across the three sites, averaging 89% ± 3 standard deviation (SD) with 245 $g \cdot ha^{-1}$ ae and 59% ± 10 SD with 123 $g \cdot ha^{-1}$ ae. Aminopyralid at lower rates, rimsulfuron, and imazapic were less consistent. Cover of other annual grasses increased in plots treated with aminopyralid at all sites. Aminopyralid has potential utility for suppressing medusahead, particularly in sites also infested with invasive members of the Asteraceae. However, the most effective rate (245 $g \cdot ha^{-1}$ ae) is registered for use only as a spot application. In situations where this rate can be justifiably used, it would be expected to give season-long control of medusahead, as well as longer-term control of thistles and other susceptible species.

Soils

Creech, M. N., Katherine Kirkman, L. and Morris, L. A. .2012. Alteration and Recovery of Slash Pile Burn Sites in the Restoration of a Fire-Maintained Ecosystem. Restoration Ecology 20: 505–516. doi: 10.1111/j.1526-100X.2011.00780.x

Abstract. Restoration practices incorporating timber harvest (e.g. to remove undesirable species or reduce tree densities) may generate unmerchantable wood debris that is piled and burned for fuel reduction. Slash pile burns are common in longleaf pine ecosystem restoration that involves hardwood removal before reintroduction of frequent prescribed fire. In this context, long-lasting effects of slash pile burns may complicate restoration outcomes due to unintended alterations to vegetation, soils, and the soil seed bank. In this study, our objectives were to (1) examine alterations to the soil seed bank, soil physical and chemical characteristics, and initial vegetation recolonization following burn and (2) determine the rate of return of soil and vegetation characteristics to pre-burn conditions. We found that burning of slash piles (composed of scores of whole trees) results in elevated

nutrient levels and significant impacts on vegetation and the soil seed bank, which remain evident for at least 6 years following burn. In this ecosystem, formerly weakly acidic soils become neutral to basic and levels of P remain significantly higher. Following an initial decrease after burn, total soil N increases with time since burn. These changes suggest that not only does pile burning create a fire scar initially devoid of biota, but it also produces an altered soil chemical environment, with possible consequences for long-term ecosystem restoration efforts in landscapes including numerous fire scars. To facilitate restoration trajectories, further adaptive management to incorporate native plant propagules or suppress encroaching hardwoods within fire scars may be warranted in fire-dependent ecosystems.

Johnson, Dale W., Roger F. Walker, Michelle McNulty, Benjamin M. Rau and Watkins W. Miller. 2012. The Long-Term Effects of Wildfire and Post-Fire Vegetation on Sierra Nevada Forest Soils. Forests 3(2): 398-416. doi:10.3390/f3020398

Abstract: This paper compares carbon (C) and nutrient contents in soils (Alfisols derived from andesite), forest floor and vegetation in a former fire (1960) and an adjacent forest in the Sagehen Watershed in the Sierra Nevada Mountains of California. Soils from the former fire (now occupied predominantly by *Ceanothus velutinus*, a nitrogen-fixing shrub) had significantly lower contents of extractable SO_4^{2-} and P (both Bray and bicarbonate) but significantly greater contents of exchangeable Ca^{2+} than the adjacent forested site (dominated by *Pinus jeffreyii*). ^{15}N data suggested that N fixation had occurred in the former fire site, but N contents did not differ between the two sites. O horizon C and nutrient contents did not differ between the two sites, but vegetation C and nutrient contents were significantly greater in the forested than former fire site. These results contrast with those from a nearby, previous study at Little Valley Nevada, also dominated by *P. jeffreyii* growing on a different soil type (Entisols derived from granite). In the Little Valley study, soil C, N, Ca^{2+}, Mg^{2+}, and K^{+} contents within the former fire (1981, now also occupied predominantly by *Ceanothus velutinus*) were greater than in the adjacent forest (*Pinus jeffreyii*) but soil extractable P contents either did not differ or were greater in the former fire. We conclude that soil parent material is an indirect but strong mediator of the effects of post-fire vegetation on soils in this region, especially with respect to soil P changes, which vary substantially between andesite- and granite-derived soils.

Rhoades, C.C., M.A. Battaglia, M.E. Rocca, and M.G. Ryan. 2012. Short- and medium-term effects of fuel reduction mulch treatments on soil nitrogen availability in Colorado conifer forests. Forest Ecology and Management 276: 231-238.

Abstract. Mechanical fuel reduction treatments have been implemented on millions of hectares of western North American forests. The redistribution of standing forest biomass to the soil surface by mulching treatments has no ecological analog, and this practice may alter soil processes and forest productivity. We evaluated the effects of mulch addition on soil nitrogen availability at 15 fuel reduction projects in the southern Rocky Mountains and Colorado Plateau regions of Colorado. Mulching treatments removed 38 Mg ha^{-1} of standing forest biomass on average and added 2–4 cm of irregular woody fragments to the O horizon. Mulching lowered maximum summer soil temperatures and increased soil moisture. The N added in mulch was equivalent to half the amount contained in untreated O horizons, and mulch had a

lower N concentration and wider C:N ratio than material of similar size in untreated areas. Plant-available soil N, measured *in situ* with ion exchange resins was reduced under heavily-mulched experimental plots the year mulching occurred, but the effect did not persist for a second year. The nitrogen content of freshly-applied mulch increased by 9, 24 and 55 kg N ha^{-1} $year^{-1}$ in plots receiving 22, 49 and 105 Mg ha^{-1} of mulch material on average. In contrast, 5-year-old mulch released N regardless of amount of mulch added. Three to five years after treatment, available N was 32% higher in mulched fuel reduction treatments compared to untreated forests. Heavy mulch application has the potential to temporarily reduce soil N availability in limited areas, but as implemented in Colorado conifer forests, fuel reduction mulch treatments increase soil N availability.

Sankey, Joel B., Matthew J. Germino, Temuulen T. Sankey and Amber N. Hoover. 2012. Fire effects on the spatial patterning of soil properties in sagebrush steppe, USA: a meta-analysis. International Journal of Wildland Fire 21(5) 545-556. http://dx.doi.org/10.1071/WF11092

Abstract. Understanding effects of changes in ecological disturbance regimes on soil properties, and capacity of soil properties to resist disturbance, is important for assessing ecological condition. In this meta-analysis, we examined the resilience of surface soil properties and their spatial patterning to disturbance by fire in sagebrush steppe of North America – a biome currently experiencing increases in wildfire due to climate change. We reviewed 39 studies that reported on soil properties for sagebrush steppe with distinct microsite (undershrub and interspace) patterning that was or was not recently burned. We estimated microsite effects for 21 soil properties and examined the effect of burning on microsite effects during the first year post-fire, before the re-establishment of vegetation. Results indicated that the spatial patterning of biogeochemical resources, in which soil surfaces beneath shrubs are enriched, is resilient to burning. However, microsite effects for soil-surface hydrologic, temperature and erosion characteristics appeared to shift following burning. These shifts appear to create a negative feedback for the spatial patterning of soil properties before vegetation recovery. Relatively long (decades–centuries) historic fire intervals in sagebrush steppe ecosystems likely reinforce spatial patterning of soil resources. However, increased fire frequency might affect the ability for soil resources to withstand change.

Switzer, Joshua M., Graeme D. Hope, Sue J. Grayston, Cindy E. Prescott. 2012. Changes in soil chemical and biological properties after thinning and prescribed fire for ecosystem restoration in a Rocky Mountain Douglas-fir forest. Forest Ecology and Management 275: 1-13.

Abstract. Practices such as thinning followed by prescribed burning, often termed 'ecosystem restoration practices', are being used in Rocky Mountain forests to prevent uncontrolled wildfire and restore forests to pre-settlement conditions. Prior to burning, surface fuels may be left or collected into piles, which may affect fire temperatures and attendant effects on the underlying soil. The objective of this study is to determine which pre-fire fuel management treatments best reduce fuel loadings without causing fire temperatures high enough to impair soil chemical and biological properties. Five fuel-management treatments were compared: large piles, small piles, cut and leave, slash-free areas around mature leave-trees, and unburned control. We measured key properties of forest floors and mineral soil (forest floor depth, soil pH, carbon and nutrient levels, and microbial abundances) prior to and

during the first year after fire, and explored relationships among fuel loadings, fire temperatures and changes in these soil properties. Fire temperatures were above 300 °C for more than 3 h in the large-pile treatment but were lower and of shorter duration in the small-pile and cut-and-leave treatments. The most severe fire effects occurred around the leave-trees where temperatures were above 200 °C for more than 2 h, the forest floor was completely consumed, and the mature trees were killed. In the forest floors, abundances of all microbial groups were reduced and pH and availabilities of Ca^{2+}, Mg^{2+} and were increased in all burned treatments. Forest floor C and N contents were reduced in burned plots by an average of 39% and 44% respectively, and availabilities of nitrate and sulphate were increased in the leave-tree areas only. There were few significant changes in mineral soil properties – pH and availabilities of , Mg^{2+} and increased in leave-tree areas whilst and K^{+} increased under large piles. Microbial abundances had not recovered to pre-fire levels in any burned treatments after one year, which may be attributed to the persistence of significant increases in pH. Prior to the fire, microbial abundances were most closely related to N concentration in the forest floor, and C and N concentrations in the mineral soil; after fire, microbial abundances were most closely related to pH of the forest floor. Forest floor consumption and attendant changes in chemical and biological properties were most closely related to pre-fire moisture content, indicating that forest-floor moisture content may be as critical as fuel loading in determining impacts of prescribed fire on soil.

Terrestrial Wildlife

Endress, Bryan A., Michael J. Wisdom, Martin Vavra, Catherine G. Parks, Brian L. Dick, Bridgett J. Naylor, Jennifer M. Boyd. 2012. Effects of ungulate herbivory on aspen, cottonwood, and willow development under forest fuels treatment regimes. Forest Ecology and Management 276: 33-40.

Abstract. Herbivory by domestic and wild ungulates can dramatically affect vegetation structure, composition and dynamics in nearly every terrestrial ecosystem of the world. These effects are of particular concern in forests of western North America, where intensive herbivory by native and domestic ungulates has the potential to substantially reduce or eliminate deciduous, highly palatable species of aspen (*Populus tremuloides*), cottonwood (*Populus trichocarpa*), and willow (*Salix* spp.). In turn, differential herbivory pressure may favor greater establishment of unpalatable conifers that serve as ladder fuels for stand-replacing fires. The resulting high fuel loads often require silvicultural fuels reductions to mitigate fire risk, which in turn may facilitate additional recruitment of deciduous species but also additional herbivory pressure. Potential interactions of ungulate herbivory with episodic disturbances of silviculture, fire, and other land uses are not well documented, but are thought to operate synergistically to affect forest dynamics. We evaluated individual and joint effects of ungulate herbivory and fuels reduction treatments in grand fir (*Abies grandis*) and Douglas-fir (*Psuedotsuga menziezii*) forests that dominate large areas of interior western North America. We applied fuels reduction treatments of mechanical thinning and prescribed fire and then evaluated the responses of aspen, cottonwood, and willow species to these treatments (N = 3) versus areas of no treatment (N = 3), and to exclusion from ungulate herbivory versus areas subjected to extant herbivory by free-ranging cattle (*Bos taurus*), elk (*Cervus elaphus*), and mule deer (*Odocoileus hemionus*). Densities of deciduous species were >4 times higher in response to fuels reduction treatments

(84.4 individuals/ha) compared to areas of no treatment (19.7 individuals/ha). Additionally, when ungulates were excluded from fuels treated sites, the density of cottonwood was >5 times higher (122.5 individuals/ha) than fuels treated sites subjected to extant herbivory (24.3 individuals/ha). Similarly, densities of *Populus* spp. and *Salix* spp. were >3 times higher (211.6 individuals/ha) on fuels treated sites excluded from ungulate herbivory versus fuels treated sites subjected to extant herbivory (66.1 stems/ha). Deciduous species subjected to extant ungulate herbivory also were significantly lower in height, canopy surface area, and canopy volume than the same species inside the ungulate exclosures. Recruitment and long-term survival of aspen, cottonwood, and willow species in coniferous forests of interior western North America require a combination of episodic disturbances such as silviculture and fire to facilitate deciduous plant recruitment, followed by reductions in grazing pressure by domestic and wild ungulates during the time intervals between episodic disturbances to facilitate plant establishment, growth and survival.

Fontaine, Joseph B., and Patricia L. Kennedy. 2012. Meta-analysis of avian and small-mammal response to fire severity and fire surrogate treatments in U.S. fire-prone forests. Ecological Applications 22:1547–1561. http://dx.doi.org/10.1890/12-0009.1.

Abstract. Management in fire-prone ecosystems relies widely upon application of prescribed fire and/or fire surrogate (e.g., forest thinning) treatments to maintain biodiversity and ecosystem function. Recently, published literature examining wildlife response to fire and fire management has increased rapidly. However, none of this literature has been synthesized quantitatively, precluding assessment of consistent patterns of wildlife response among treatment types. Using meta-analysis, we examined the scientific literature on vertebrate demographic responses to burn severity (low/moderate, high), fire surrogates (forest thinning), and fire and fire surrogate combined treatments in the most extensively studied fire-prone, forested biome (forests of the United States). Effect sizes (magnitude of response) and their 95% confidence limits (response consistency) were estimated for each species-by-treatment combination with two or more observations. We found 41 studies of 119 bird and 17 small-mammal species that examined short-term responses (≤4 years) to thinning, low/moderate- and high-severity fire, and thinning plus prescribed fire; data on other taxa and at longer time scales were too sparse to permit quantitative assessment. At the stand scale (<50 ha), thinning and low/moderate-severity fire demonstrated similar response patterns in these forests. Combined thinning plus prescribed fire produced a higher percentage of positive responses. High-severity fire provoked stronger responses, with a majority of species possessing higher or lower effect sizes relative to fires of lower severity. In the short term and at fine spatial scales, fire surrogate forest-thinning treatments appear to effectively mimic low/moderate-severity fire, whereas low/moderate-severity fire is not a substitute for high-severity fire. The varied response of taxa to each of the four conditions considered makes it clear that the full range of fire-based disturbances (or their surrogates) is necessary to maintain a full complement of vertebrate species, including fire-sensitive taxa. This is especially true for high-severity fire, where positive responses from many avian taxa suggest that this disturbance (either as wildfire or prescribed fire) should be included in management plans where it is consistent with historic fire regimes and where maintenance of regional vertebrate biodiversity is a goal.

Roloff, Gary J., Stephen P. Mealey, and John D. Bailey. 2012. Comparative hazard assessment for protected species in a fire-prone landscape. Forest Ecology and Management 277: 1-10.

Abstract. We conducted a comparative hazard assessment for 325,000 ha in a fire-prone area of southwest Oregon, USA. The landscape contains a variety of land ownerships, fire regimes, and management strategies. Our comparative hazard assessment evaluated the effects of two management strategies on crown fire potential and northern spotted owl (*Strix occidentalis* caurina) conservation: (1) no action, and (2) active manipulation of hazardous fuels. Model simulations indicated that active management of sites with high fire hazard was more favorable to spotted owl conservation over the long term (75 years) than no management, given our modeling assumptions. Early in the model simulation, young seral stages were mostly responsible for high fire hazard, and active management in young stands tended to perpetuate that hazard. Later in the simulation, older seral stages accounted for most of the high fire hazard and active management could be used to ameliorate that hazard. At any given time period, ⩽8% of the landscape was identified for treatment. Fire hazard fluctuated over time depending on vegetation regeneration, maturation, and response to treatments. Active management resulted in greater numbers of potential spotted owl territories in lower fire hazard conditions, particularly during later years of our simulation. Our results support the contention that short term risks to protected species from active management can be less than longer term risk of no management in fire-prone landscapes. Thus, a short term, risk averse strategy for protected species in fire-prone landscapes may not be the best long term alternative for conservation. We caution that this finding warrants landscape-level field evaluation and structured adaptive management and monitoring prior to broad scale adoption as environmental policy.

Woodlands and Rangelands

Davies, G. M., J. D. Bakker, E. Dettweiler-Robinson, P. W. Dunwiddie, S. A. Hall, J. Downs, and J. Evans. 2012. Trajectories of change in sagebrush steppe vegetation communities in relation to multiple wildfires. Ecological Applications 22:1562–1577. http://dx.doi.org/10.1890/10-2089.1.

Abstract. Repeated perturbations, both biotic and abiotic, can lead to fundamental changes in the nature of ecosystems, including changes in state. Sagebrush steppe communities provide important habitat for wildlife and grazing for livestock. Fire is an integral part of these systems, but there is concern that increased ignition frequencies and invasive species are fundamentally altering them. Despite these issues, the majority of studies of fire effects in systems dominated by *Artemisia tridentata wyomingensis* have focused on the effects of single burns. The Arid Lands Ecology Reserve (ALE), in south-central Washington (USA), was one of the largest contiguous areas of sagebrush steppe habitat in the state until large wildfires burned the majority of it in 2000 and 2007. We analyzed data from permanent vegetation transects established in 1996 and resampled in 2002 and 2009. Our objective was to describe how the fires, and subsequent postfire restoration efforts, affected communities' successional pathways. Plant communities differed in response to repeated fire and restoration; these differences could largely be ascribed to the functional traits of the dominant species. Low-elevation communities, previously dominated by obligate seeders, moved furthest from their initial composition and were dominated by weedy, early-successional species in 2009. Higher-elevation

sites with resprouting shrubs, native bunchgrasses, and few invasive species were generally more resilient to the effects of repeated disturbances. Shrub cover has been almost entirely removed from ALE, although there was some recovery where communities were dominated by resprouters. *Bromus tectorum* dominance was reduced by herbicide application in areas where it was previously abundant, but it increased significantly in untreated areas. Several resprouting species, notably *Phlox longifolia* and *Poa secunda*, expanded remarkably following competitive release from shrub canopies and/or abundant *B. tectorum*. Our results suggest that community dynamics can be understood through a state and transition model with two axes (shrub/grass and native/invasive abundance), although such models also need to account for differences in plant functional traits and disturbance regimes. We use our results to develop a conceptual model that will be validated with further research.